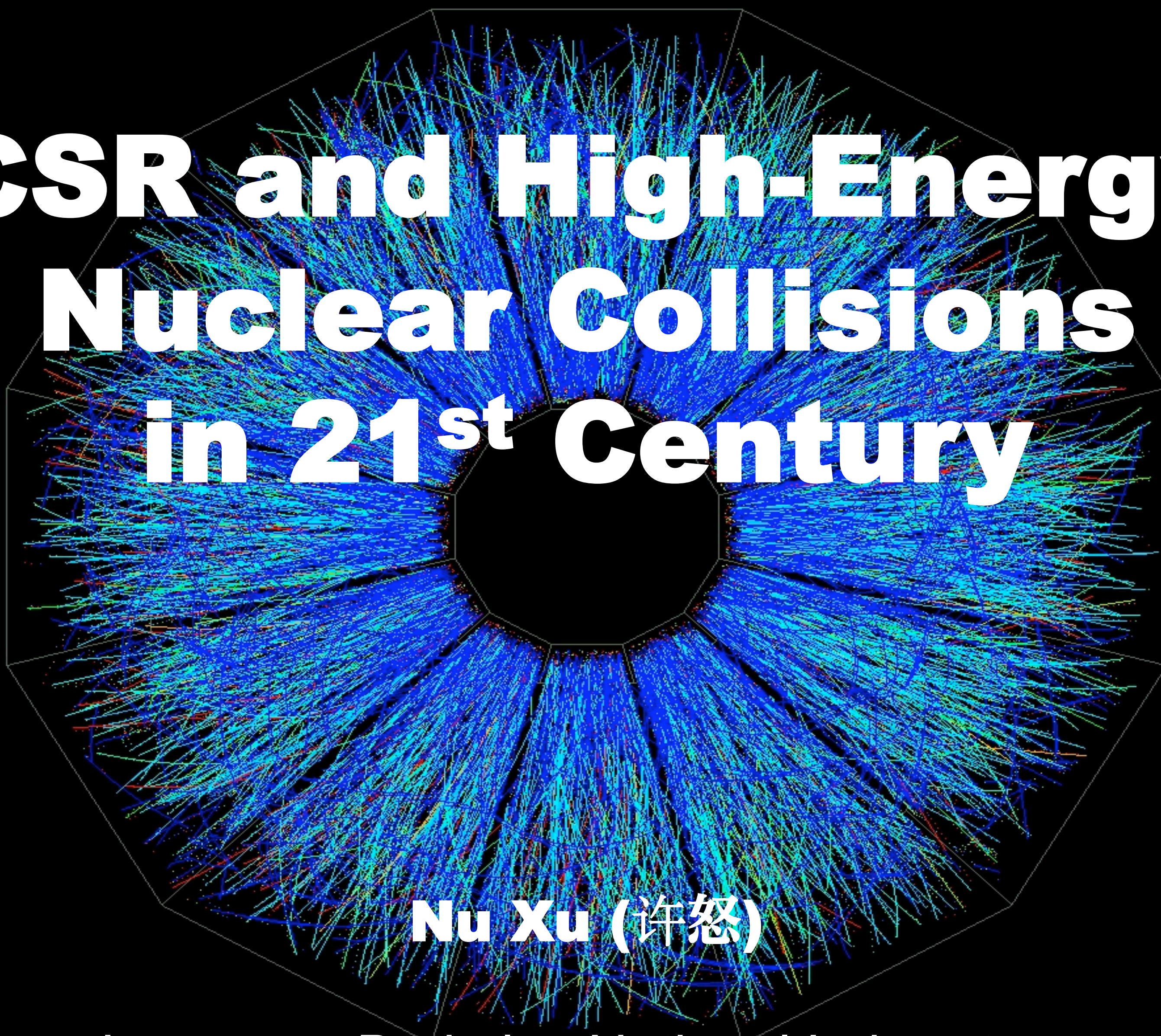
CSR and High-Energy Nuclear Collisions in 21st Century



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Outline

(1) Introduction – the question

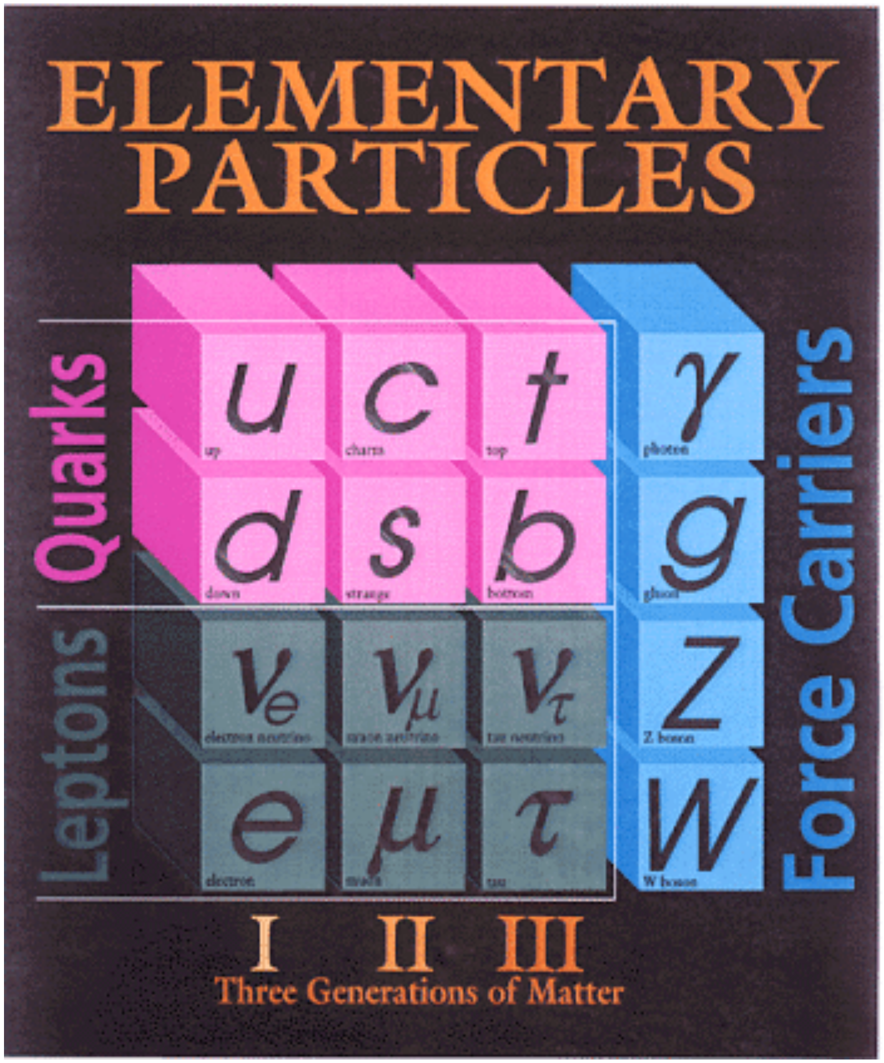
- the ***QCD phase diagram***

(2) Recent work related to CSR

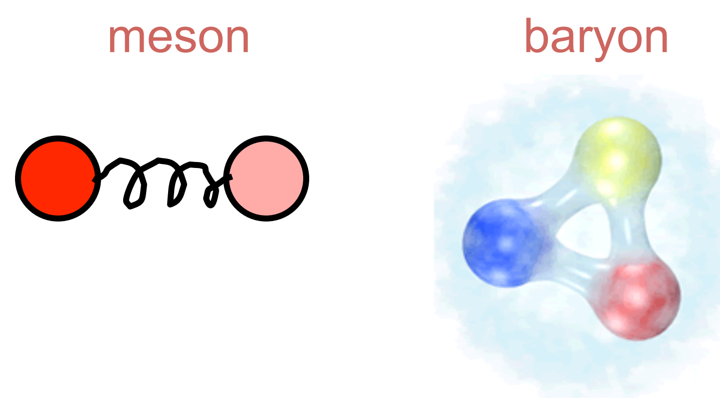
- Charm production at higher energy
- Preparations for U+U collisions at CSR

(3) Status at CSR and Outlook

Quantum Chromodynamics

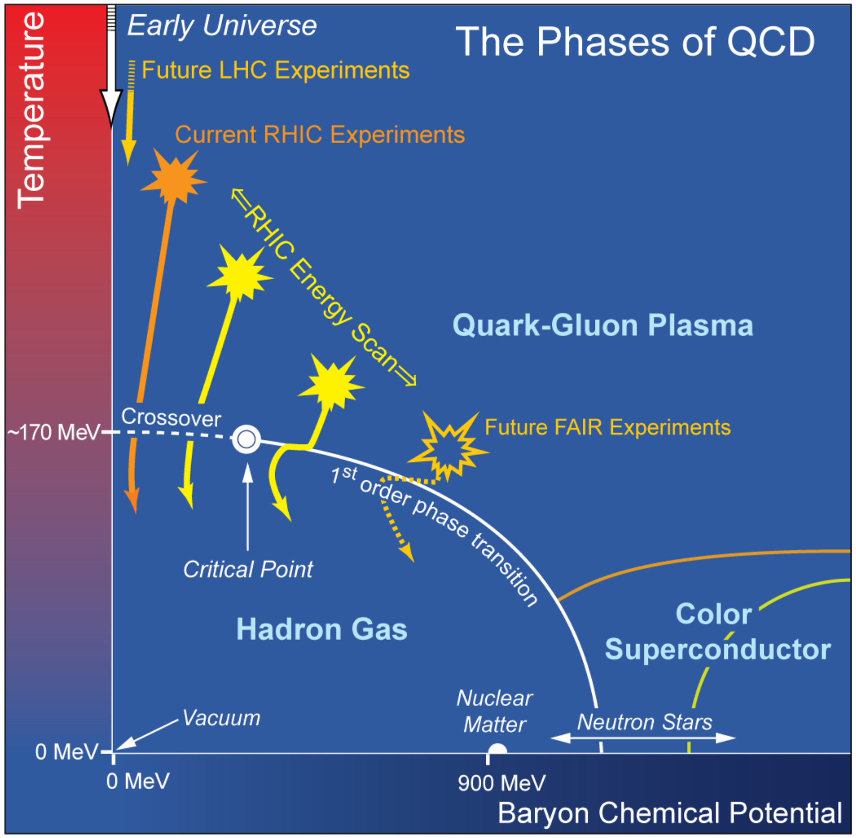


1) Quantum Chromodynamics (QCD) is the established theory of strongly interacting matter.
2) Gluons hold quarks together to from hadrons:



3) Gluons and quarks, or partons, typically exist in a color singlet state: ***confinement.***

The QCD Phase Diagram



- LGT prediction on the transition temperature, T_C ~ 170 MeV.

- LGT calculation, universality, and models point to the existence of the critical point on the QCD phase diagram* at finite baryon chemical potential.

- Experimental evidence for either the critical point or 1st order transition is important for our knowledge of the QCD phase diagram*.

*** Thermalization is assumed**

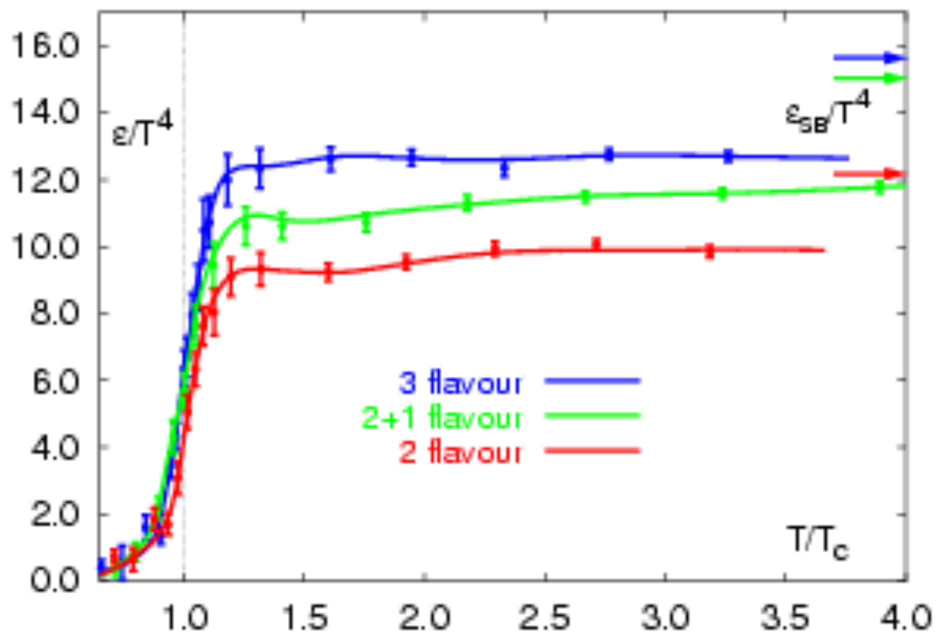
*Stephanov, Rajagopal, and Shuryak, PRL **81**, 4816(98)*
*Rajagopal, PR **D61**, 105017 (00)*
http://www.er.doe.gov/np/nsac/docs/Nuclear-Science.Low-Res.pdf

STAR's plan:

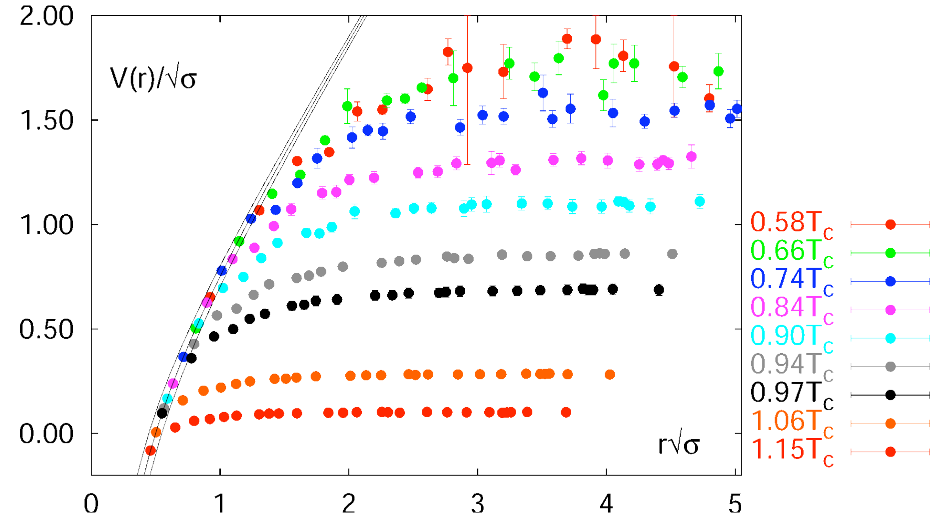
run10: RHIC Beam Energy Scan
run11: Heavy Quark measurements

Lattice QCD Predictions

Energy density



Heavy quark potential



Temperature

Left: Large increase in energy density at **T_C ~ 170 MeV**.
Not reach the non-interacting S.B. limit.

Right: Heavy quark potentials are melted at high temperature.

F. Karsch et al. Nucl. Phys. ***B524****, 123(02). Z. Fodor et al,* ***JHEP*** *0203:014(02).*
C.R. Allton et al, Nucl. Rev. ***D66****, 074507(02). F. Karsch, Nucl. Phys.* ***A698****, 199c(02).*

Issues

Theoretical tools:

(1) At high energy, T ≥ 120 MeV, Lattice calculation is the main focus

(2) At lower energy, no calculations base on first principles. Experiment is the only method to make progress in understanding.

High-Energy Nuclear Collisions

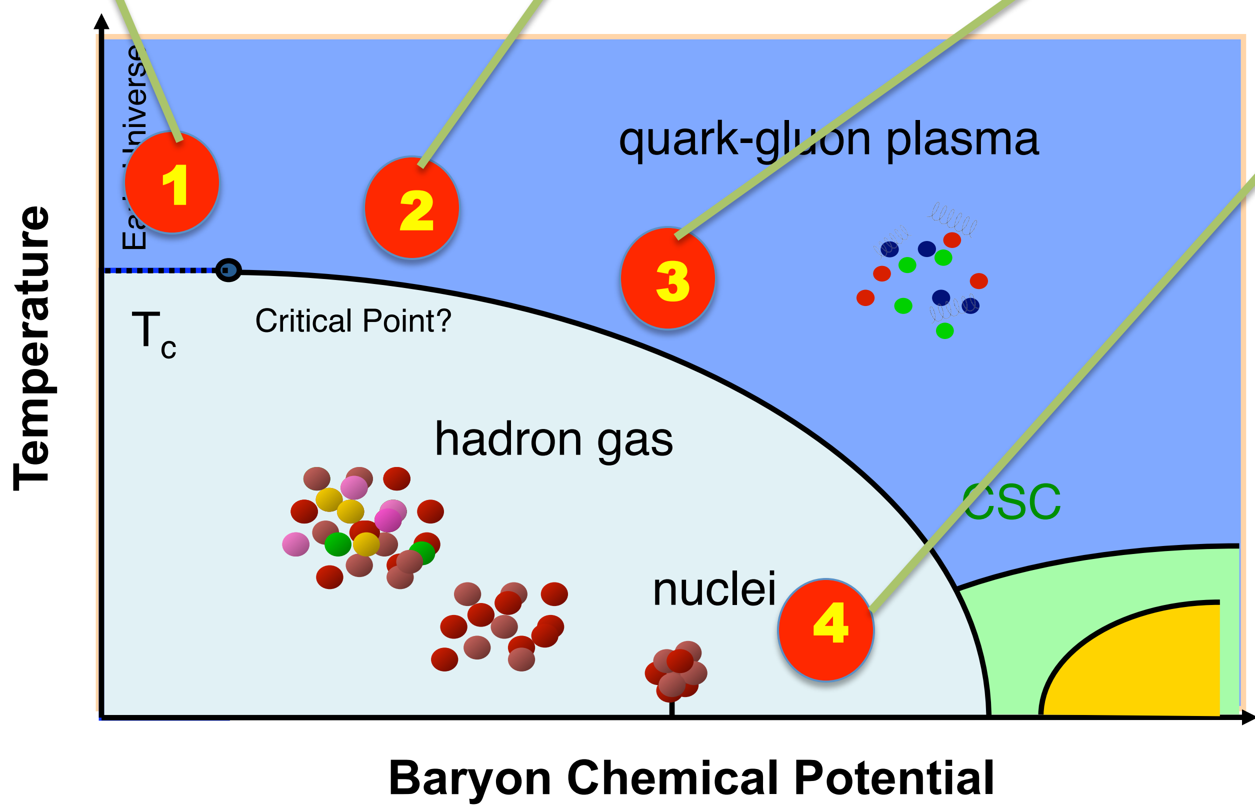
Explore the QCD landscape and the structure of the matter with partonic degrees of freedom.

1 Energy Frontier
T_C
LHC, RHIC

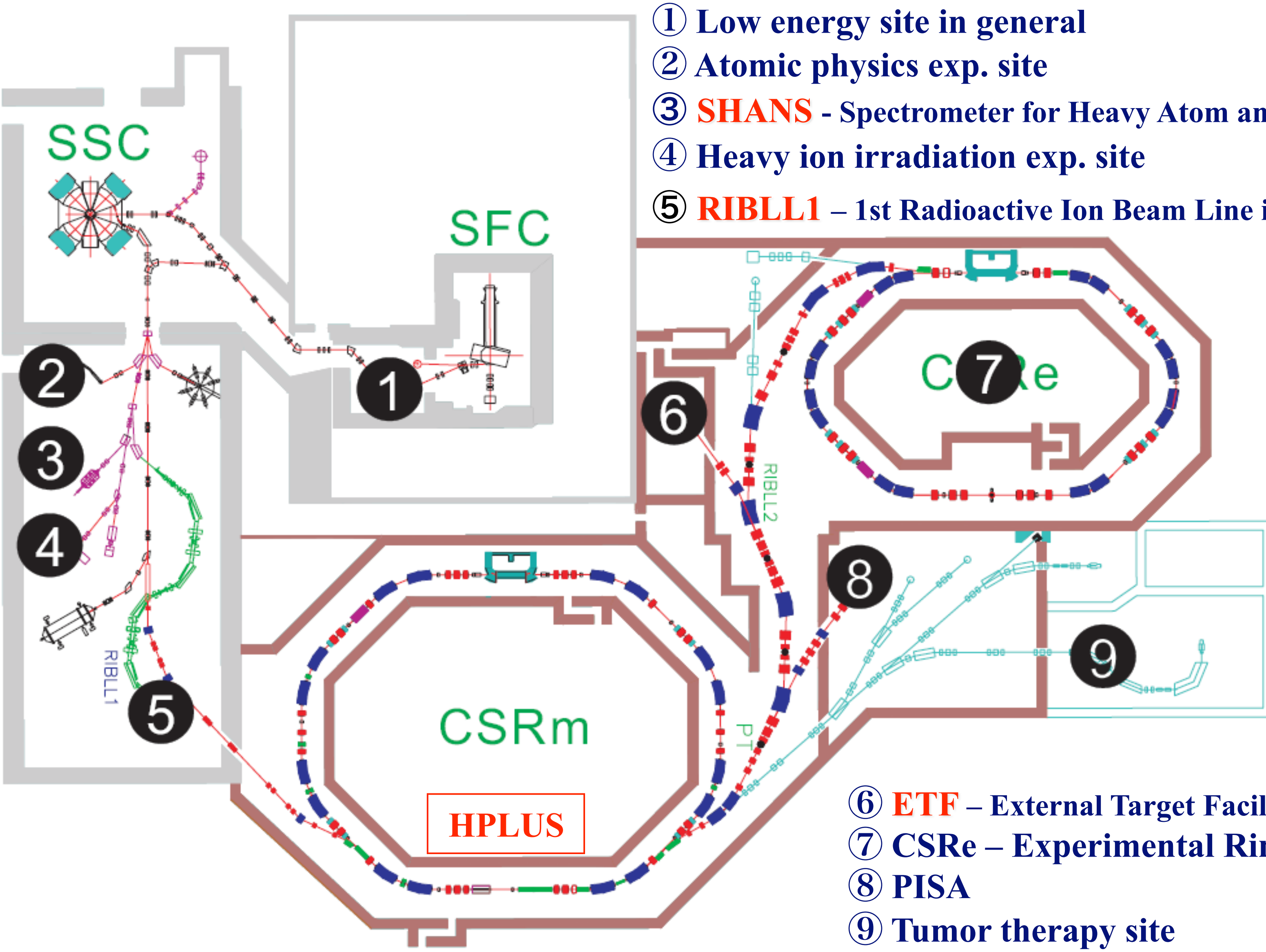
2 Density Frontier
T_E
RHIC, FAIR

3 Baryon Density
1^{st} order p.b.
FAIR, NICA, CSR

4 Small-x, large gluon density
CGC
EIC



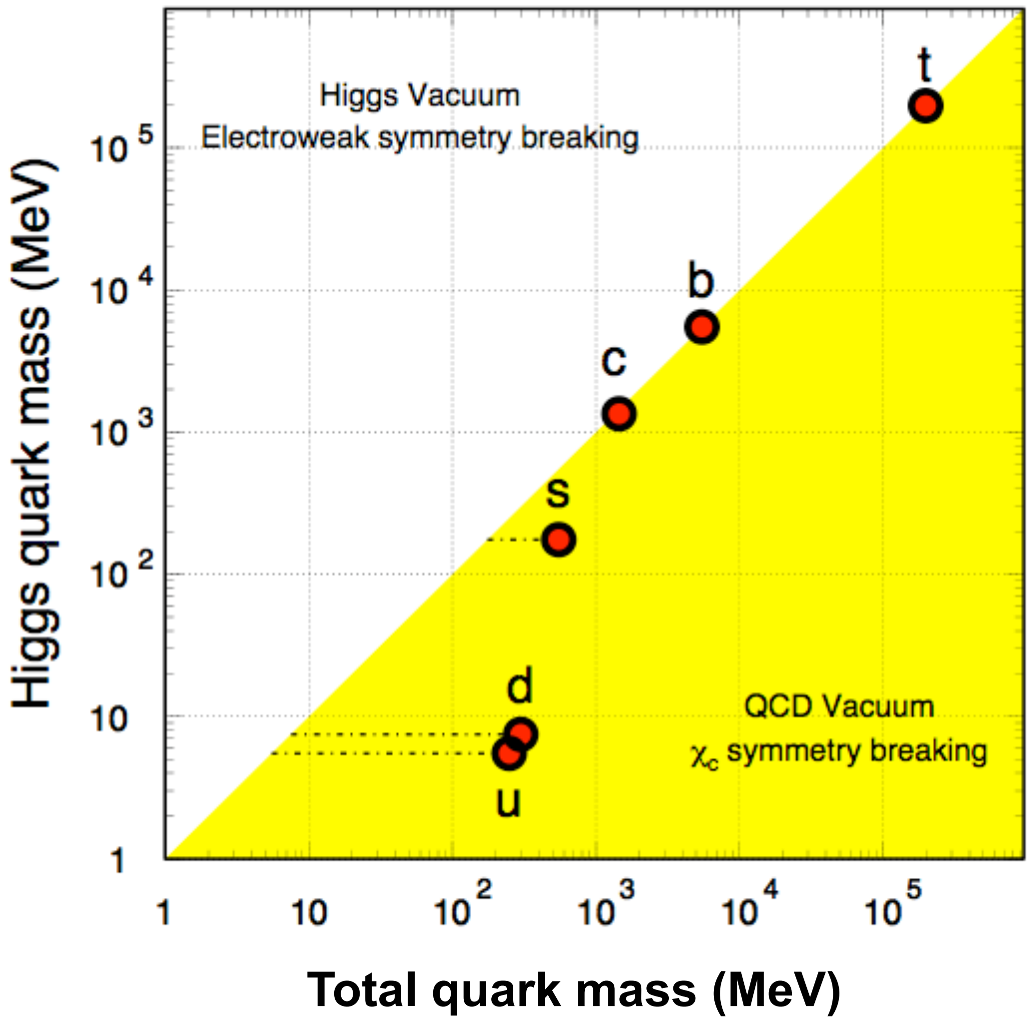
Heavy Ion Research Facility at Lanzhou



① Low energy site in general
② Atomic physics exp. site
③ SHANS - Spectrometer for Heavy Atom and Nuclear Structure
④ Heavy ion irradiation exp. site
⑤ RIBLL1 – 1st Radioactive Ion Beam Line in Lanzhou

⑥ ETF – External Target Facility at CSR
⑦ CSRe – Experimental Ring
⑧ PISA
⑨ Tumor therapy site

Quark Masses & HI Collisions



1) Higgs mass: electro-weak symmetry breaking. (current quark mass)
2) QCD mass: Chiral symmetry breaking. (constituent quark mass)

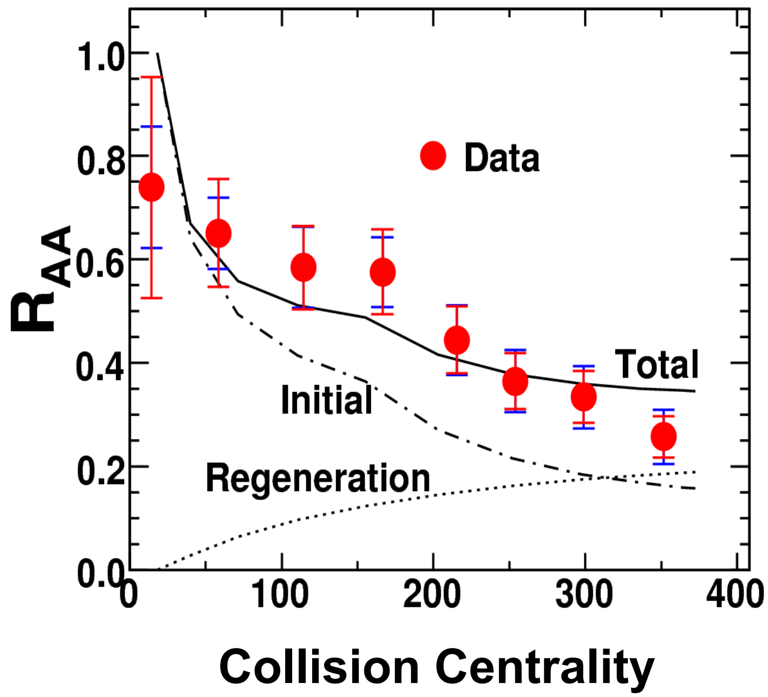
⇨ New mass scale compared to the excitation of the system.

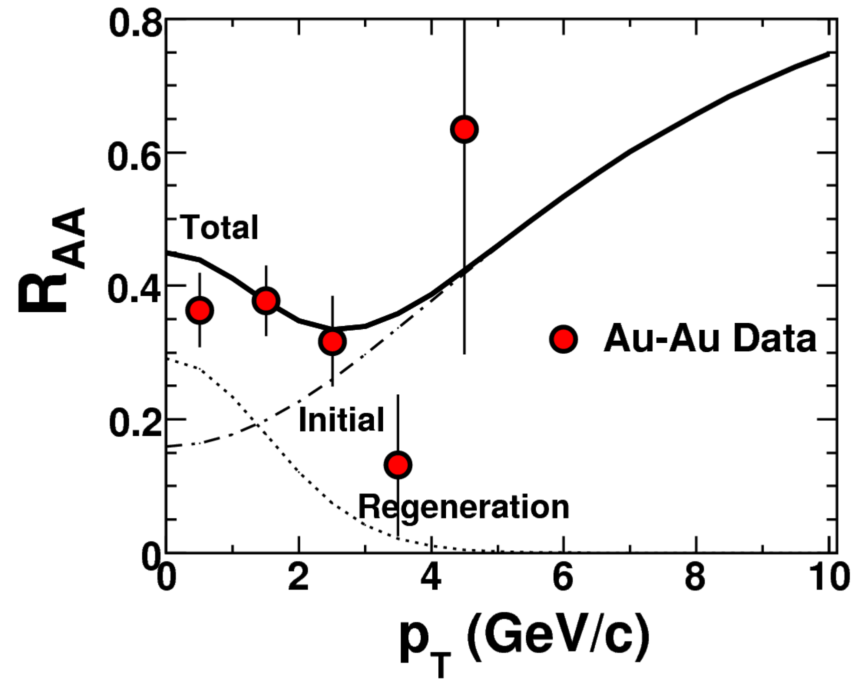
⇨ Important tool for studying properties of the hot/dense medium at RHIC.

⇨ Test pQCD predictions at RHIC.

R_{AA} versus p_T

200 GeV Au + Au Collisions at RHIC

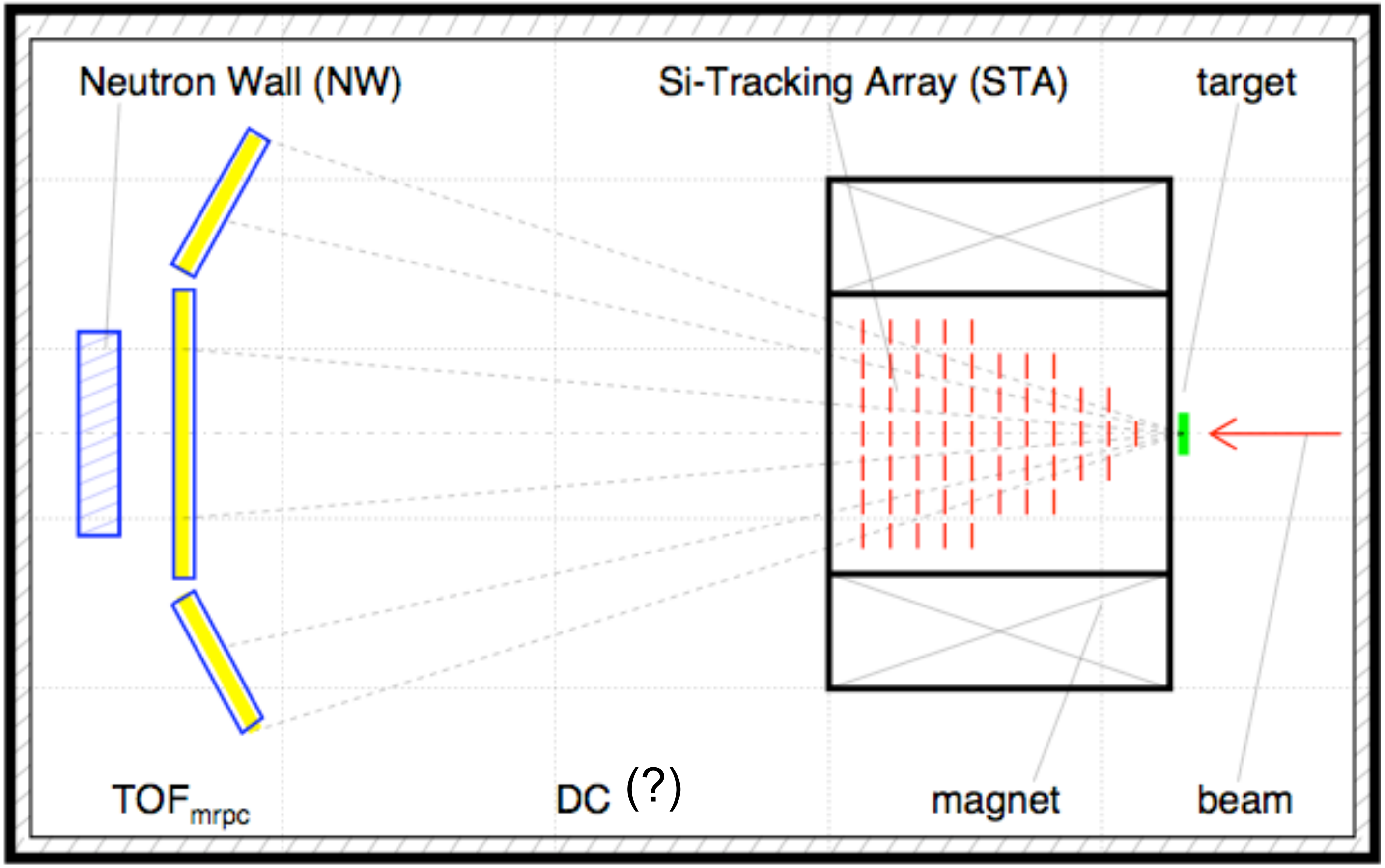




1) **Left-plot:** At the most central collision, both initial and regeneration are important.

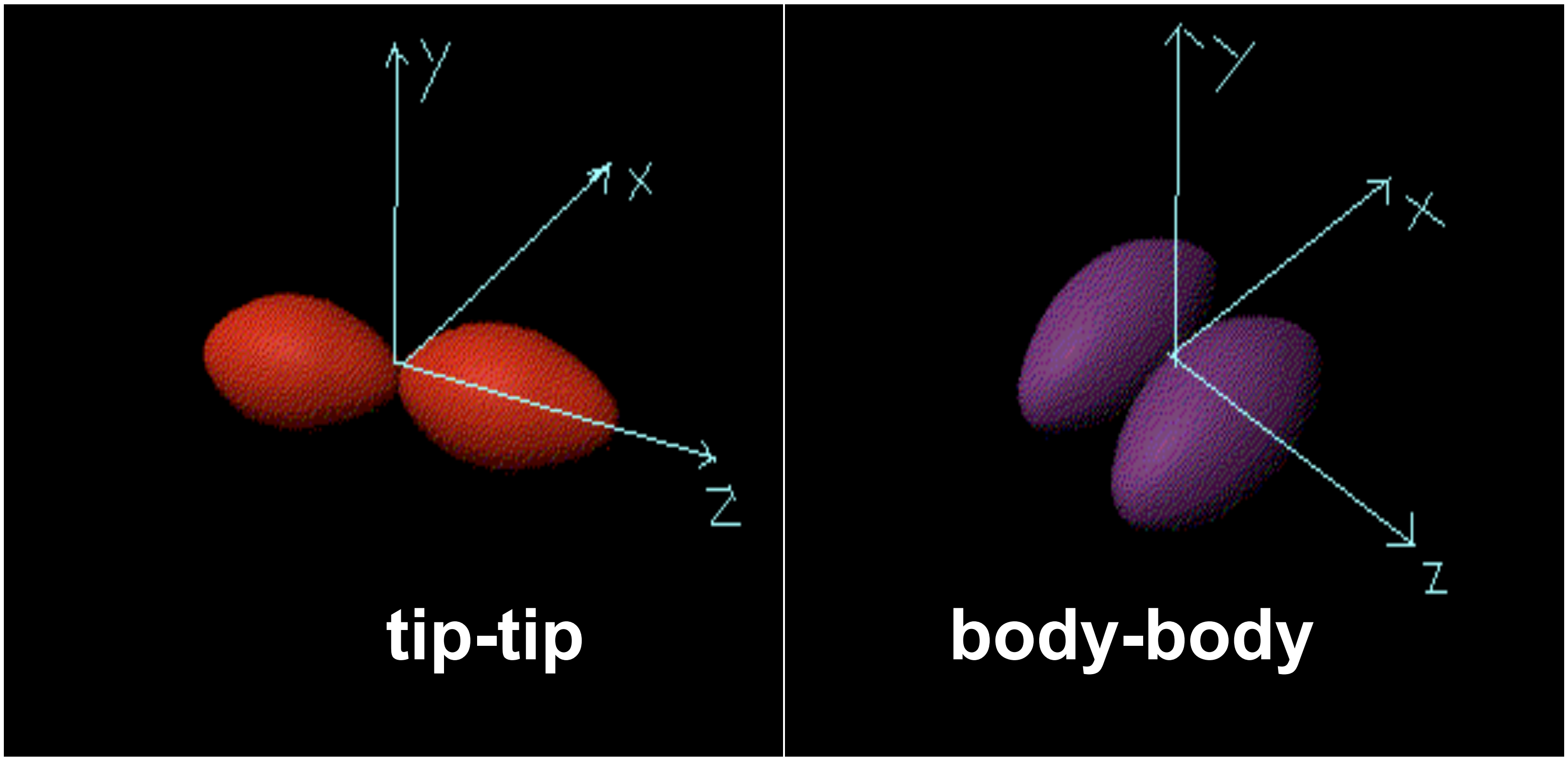
2) **Right-plot:** The low p_T region is controlled by both initial production and regeneration, while high p_T region is governed by only initial production including the Cronin effect and leakage effect.

ETF Phase-II 2005

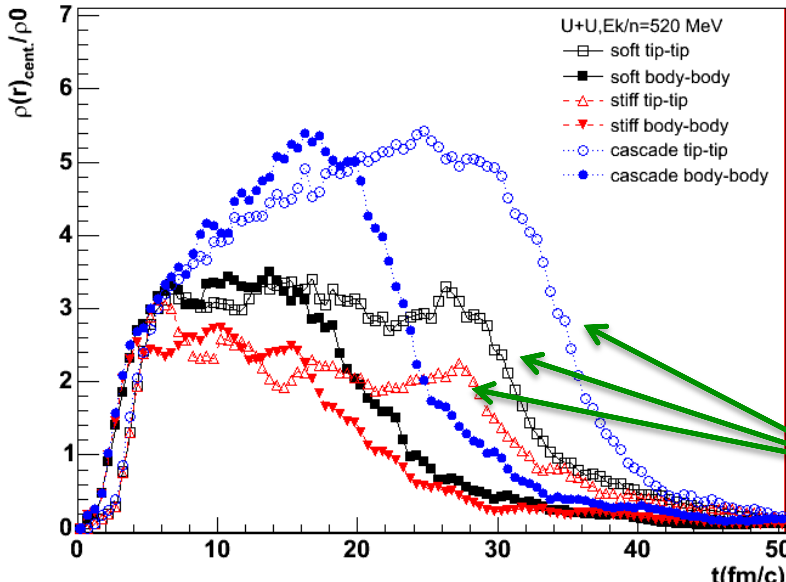


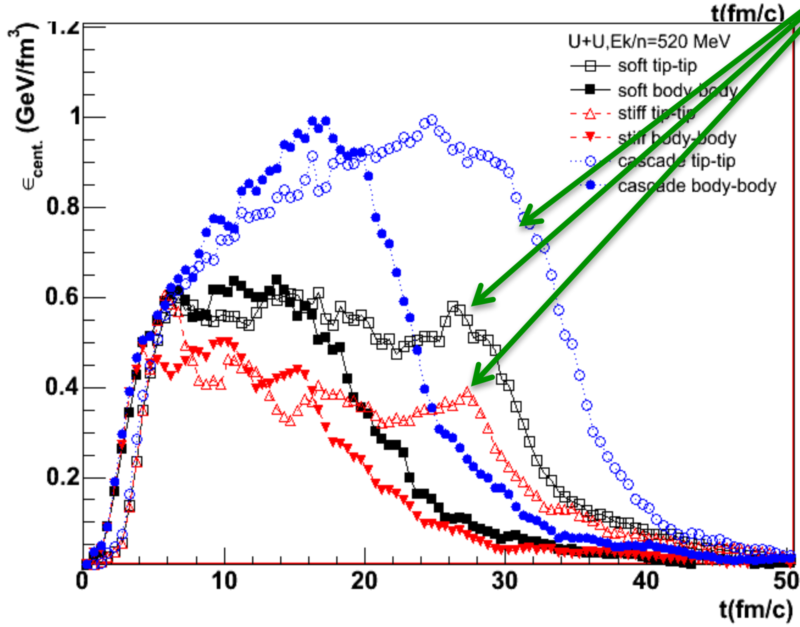
ETF (External Target Facility)

U+U Collisions: Unique



Time Dependence of the U+U Collisions





$$\frac{\varepsilon_{\max}}{\varepsilon_0} \approx \frac{\rho_{\max}}{\rho_0} \approx 2.5$$

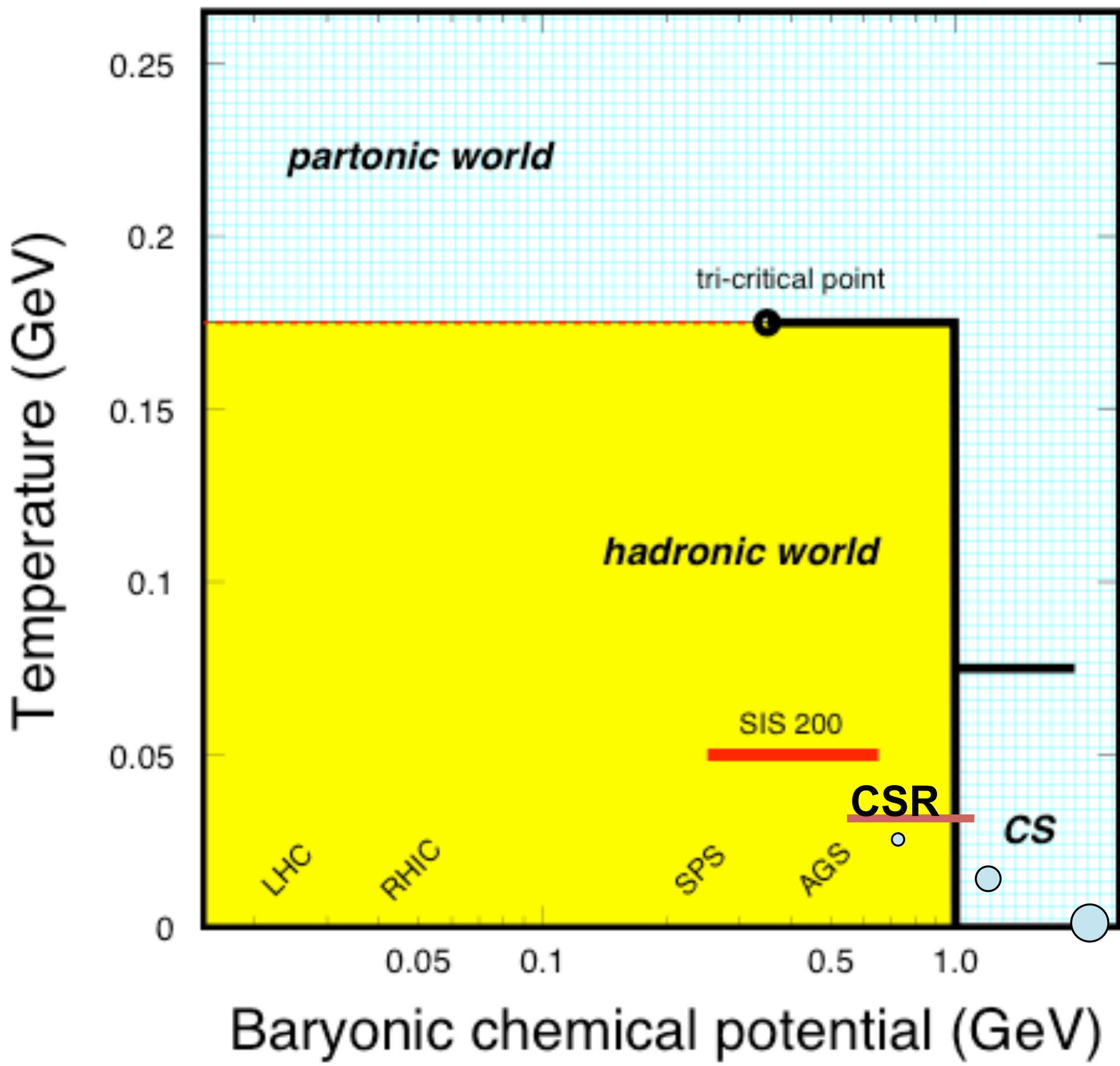
In case of tip-tip collisions

- Longer time duration

- Larger energy & particle densities

Simulations done by Kejun Wu, IOPP, 2007

QCD Phase Diagram



The location of the critical point is highly uncertain - experimental inputs are essential.

RHIC seems to be in the region of 'fast' cross-over.

To 'see' the transition from hadronic world to partonic world, one must cross the 'boundary' - ***energy scan at the region below RHIC energies.***

???

Key Physics Observables

1) ***Hadron mass effects:***

ρ, ω, η, ϕ-meson => e^+e^-, $\pi^+\pi^-$

2) ***Strangeness production:***

K^+ production, centrality dependence

3) ***Isospin effects:*** π^+/π^-, n/p ratios

4) ***Critical behavior:***

Multiplicity & $\langle p_T \rangle$ fluctuations, flow,
net-proton Kurtosis

Beam: $A \geq 100 - 238$ $E_{beam} \geq 0.5\text{-}0.7$ GeV

Essential Goals of ETE Program

2005

1) Develop detector systems for modern nuclear physics program, new tech is important. Testing facility for other program.

2) Complimentary with other physics programs, NOT necessarily aimed at major discovers. Part of the wider astrophysics, nuclear, and particle physics program.

3) TRAINING NEXT GENERATION PHYSICISTS

Recent Publications

兰州CSR能区~(238)U~(238)U碰撞椭圆流模拟研究
吴科军; 罗晓峰; 刘峰 高能物理与核物理, High Energy Physics and Nuclear Physics, **V31** 617(2007).

Nuclear stopping and sideward-flow correlation from 0.35*A* to 200*A* GeV
Xiao-Feng Luo, Ming Shao, **Xin Dong**, and Cheng Li PHYSICAL REVIEW C **78**, 031901(R) (2008)

Stopping effects in U+U collisions with a beam energy of 520 MeV/nucleon
Xiao-Feng Luo, **Xin Dong**, Ming Shao, **Ke-Jun Wu**, Cheng Li, Hong-Fang Chen and Hu-Shan Xu
Phys. Rev. C **76**, 044902 (2007).

Event selection in CSR-ETF U+U collision
罗晓峰; 邵明; 李澄 中国物理 C **32**, 17(2008).

A new type of Time-Of-Propagation (TOP) Cherenkov detector for particle identification
言杰; 邵明; 李澄 中国物理 C 2008 32 (S2): 225—228

Monte-Carlo Simulation and Study of Sideward Flow for ^{238}U+^{238}U Collisions at CSR Energy Area
WU Ke-Jun and LIU Feng, HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS, V31, 1022(2007).

Equation of State Study in UU collisions at CSR
Z.G. Xiao, Proceedings of QM06, J.P. G34, (2007).

Determination of Orientations in Deformed U–U Collisions at 0.52 GeV/u
WU Ke-Jun, XIE Fei, ZHOU You, LIU Feng, XU Nu, Chin. Phys. Lett. **25**, 3204(2008).

Outlook

Issues: CSR still can do first class physics

If

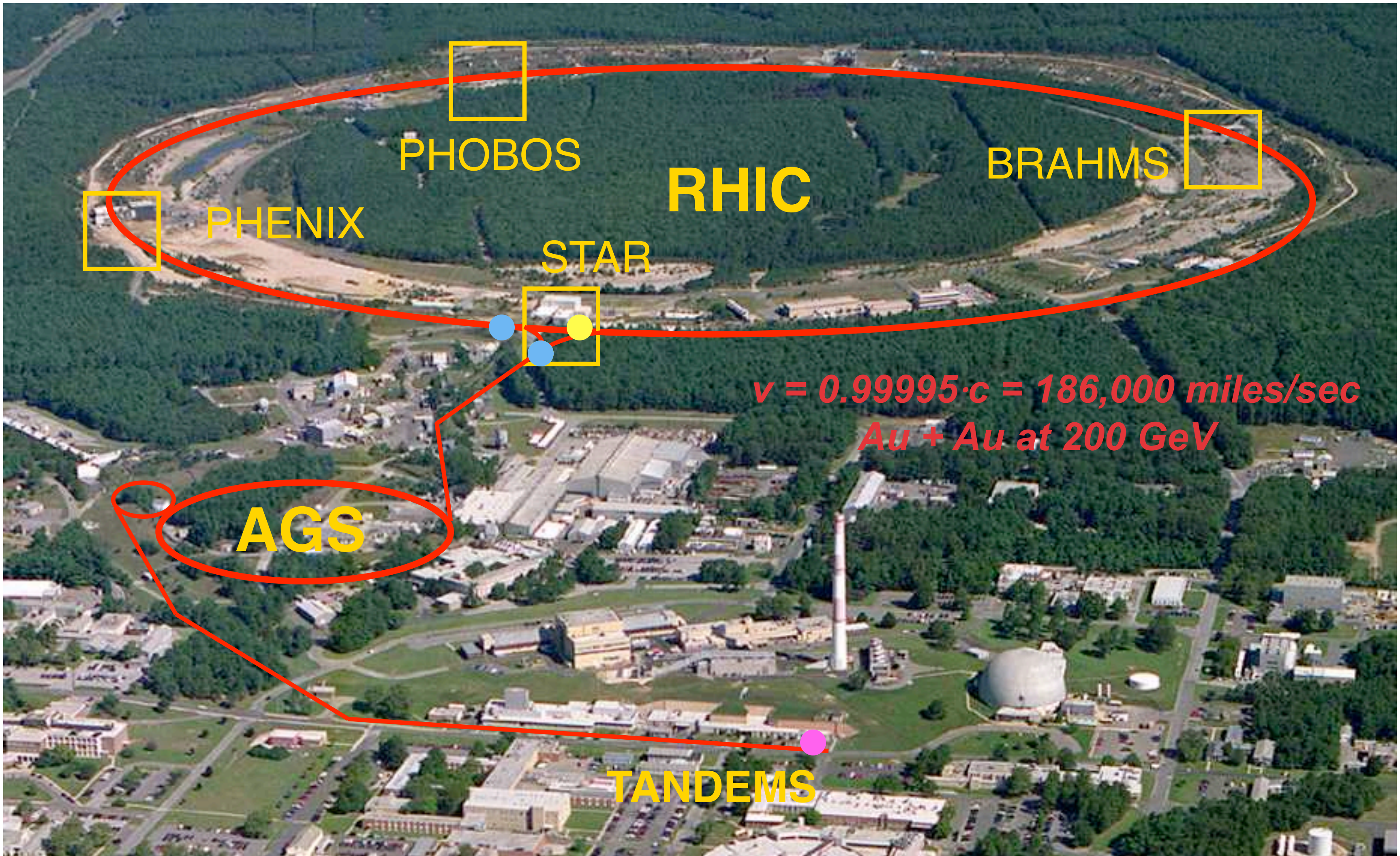
(1) Produce useable U beam before 2012, and

(2) A team of **researchers** + the **ETF**: Measure ***U+U*** collisions and looking for the effect of phase boundary. In the future, we may request an upgrade of the accelerator to provide U beam at ~ 1 GeV/u.

A list of World Facilities for High-Energy Nuclear Collisions

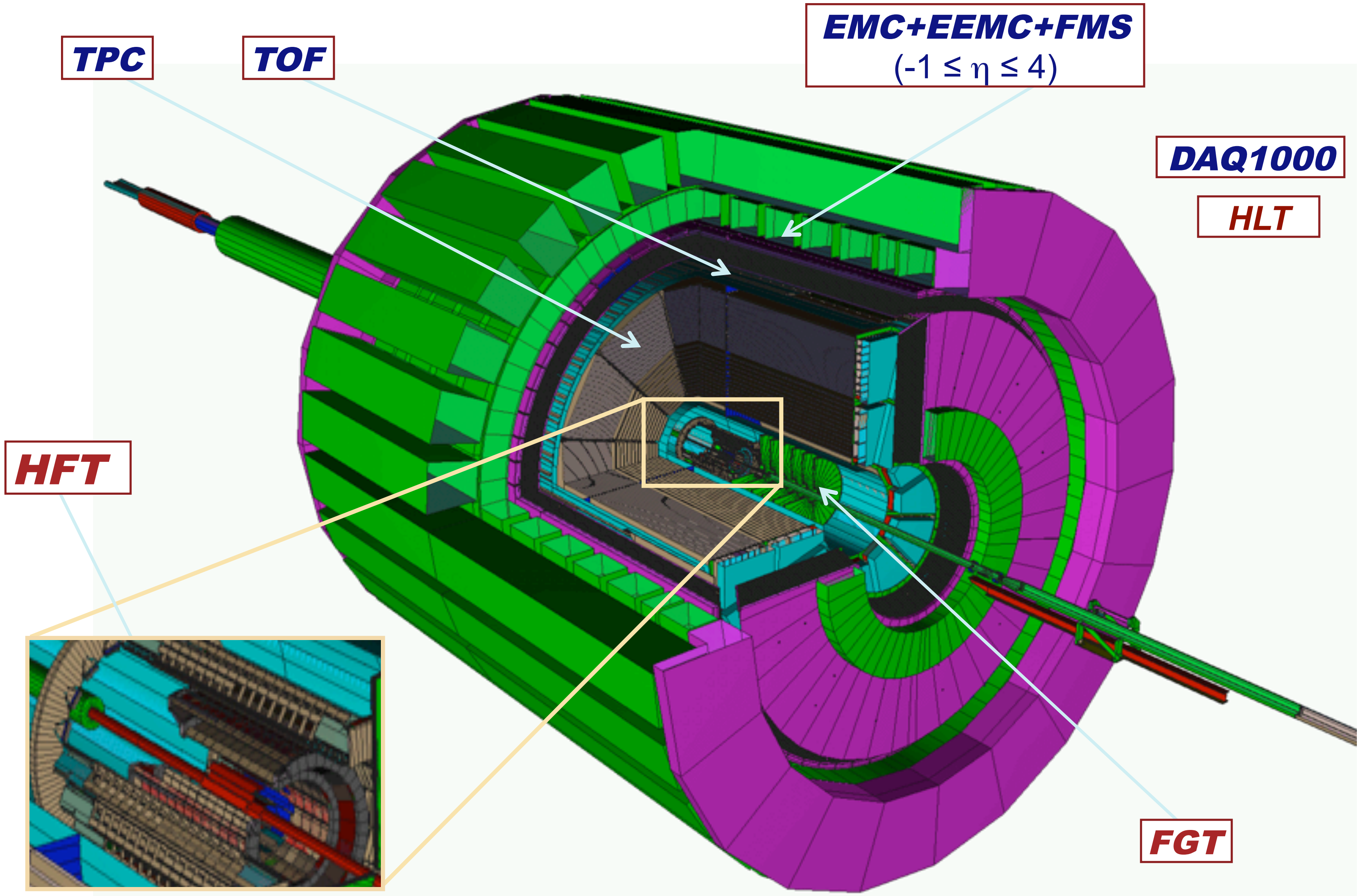
Relativistic Heavy Ion Collider (RHIC)

Brookhaven National Laboratory (BNL), Upton, NY

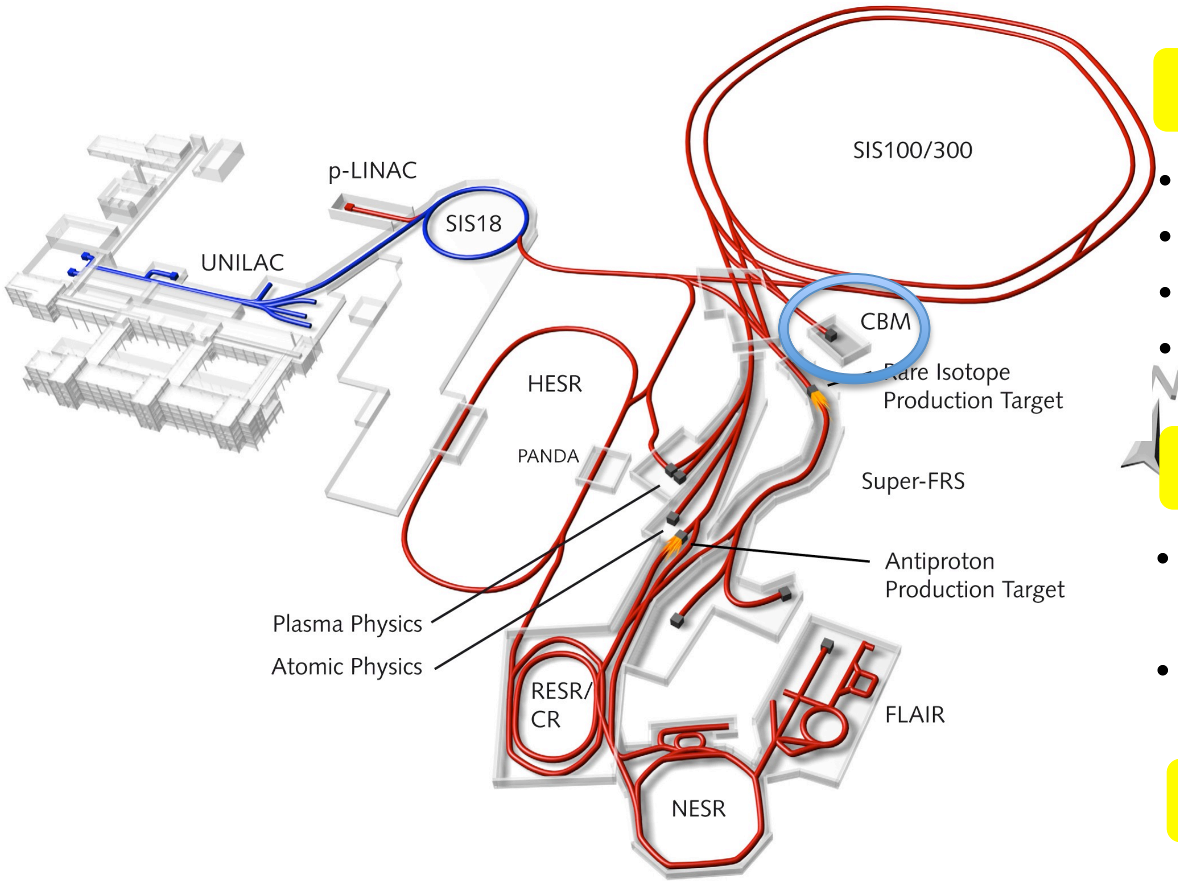


Animation M. Lisa

STAR Detectors: *Full 2π particle identification!*



Facility for Antiproton and Ion Research (FAIR)



primary beams

- 5×10^{11}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- factor 100-1000 increased intensity
- 4×10^{13}/s 90 GeV protons
- 10^{10}/s ^{238}U 35 GeV/u (Ni 45 GeV/u)

secondary beams

- rare isotopes 1.5 - 2 GeV/u;
  factor 10 000 increased intensity
- antiprotons 3(0) - 30 GeV

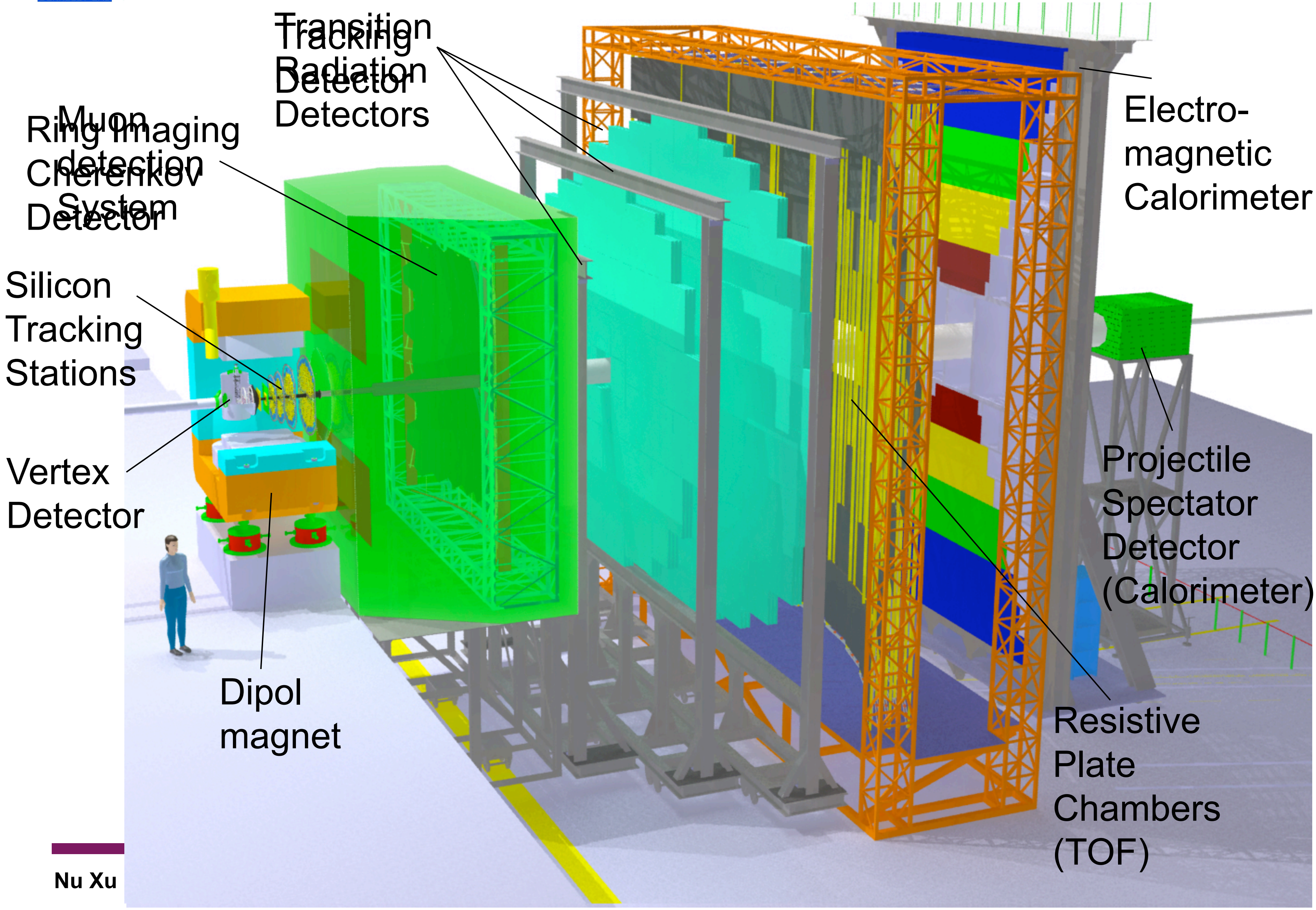
storage and cooler rings

- beams of rare isotopes
- e – A Collider
- 10^{11} stored and cooled antiprotons
  0.8 - 14.5 GeV

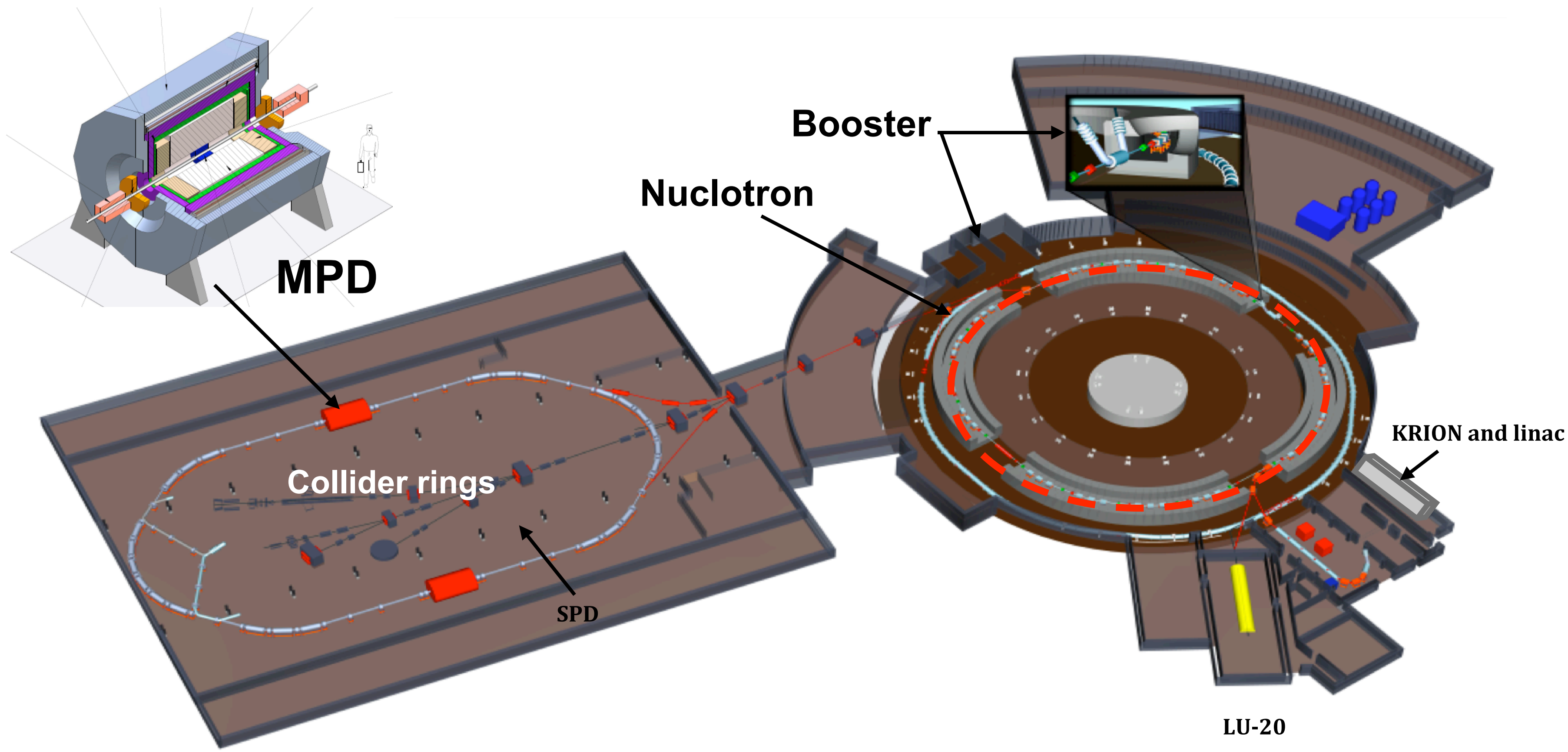
accelerator technical challenges

- Rapidly cycling superconducting magnets
- high energy electron cooling
- dynamical vacuum, beam losses

The Compressed Baryonic Matter Experiment



NICA (collider)



U+U, up to $\sqrt{s_{NN}}$ = 11 GeV
Planned to operator in 2015